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USE OF SYMBOLS IN EXPRESSING THE QUANTITATIVE CLASSIFICATION OF IGNEOUS ROCKS

WHITMAN CROSS

In a recent publication F. W. Clarke[1] has given, among various geochemical data, a new average for the existing chemical analyses of igneous rocks of the world, together with other averages for continents, countries, or districts. Clarke also gives a table, prepared by Iddings, showing by names and symbols the quantitative classification of magmas corresponding in composition to those averages. Speaking of these averages as representing magmas or rocks, it is a fact, of no special significance in itself, that many of them chance to fall very near boundary lines of several divisions of the quantitative system. Consequently the simple names and symbols of Clarke's table fail to show satisfactorily the true systematic relations of such rocks. These relations may, however, be very clearly expressed by means of the elaborated symbols, proposed since the publication of Clarke's paper, by the authors of the quantitative system.[2] The efficacy of these symbols in expressing certain relations may be illustrated by showing their application to the averages of Clarke.

As the basis for the calculations to follow and to further disseminate the interesting averages made by Clarke, they are repeated in the accompanying table. Water and several rare or unimportant constituents have been omitted by Clarke and the remainders calculated to 100 per cent. The capital letters by which Clarke designates individual averages in his tables have been retained.

The normative ratios of the table on p. 760 give the data by which rocks of these average compositions may be accurately classified in the quantitative system. From these ratios the elabo-

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[1] "Some Geochemical Statistics," *Proc. Am. Phil. Soc.*, XLI (1912), 214–34.

[2] W. Cross, J. P. Iddings, L. V. Pirsson, and H. S. Washington, "Modifications of the Quantitative System of Classification of Igneous Rocks," *Jour. Geol.*, XX (1912), 550–61.

AVERAGES OF CHEMICAL ANALYSES OF ROCKS, CLARKE

	A	B	C	E	F	G	H	I	J	L	M	N	O	P	Q
SiO_2	61.13	60.49	58.83	61.68	59.16	61.22	62.87	62.20	61.47	60.84	58.83	60.18	59.89	61.13	60.76
Al_2O_3	15.03	15.81	15.97	15.41	15.17	16.35	16.66	15.87	15.63	16.70	15.76	15.88	16.07	16.29	15.87
Fe_2O_3	3.50	4.90	3.36	2.67	2.16	3.30	2.67	2.12	2.67	3.75	3.96	3.90	4.18	3.76	3.40
FeO	4.38	2.77	3.91	3.55	5.36	2.58	2.40	3.46	3.22	2.68	3.75	3.44	3.18	2.93	3.19
MgO	2.86	3.81	3.88	3.97	4.92	3.47	2.06	3.93	4.02	2.10	4.09	2.82	3.59	3.18	3.78
CaO	4.81	4.95	5.27	5.02	5.69	4.95	4.01	6.06	5.12	4.39	5.73	5.83	5.30	5.54	5.23
Na_2O	3.75	3.26	3.95	3.49	3.46	3.83	4.11	3.49	3.62	4.98	3.74	3.36	3.70	4.01	3.67
K_2O	3.32	2.84	3.19	3.07	2.76	3.22	4.10	1.92	3.06	3.68	3.18	4.17	3.25	2.16	3.08
TiO_2	0.78	0.53	1.05	0.77	0.98	0.69	0.74	0.58	0.81	0.63	0.67	0.10	0.51	0.66	0.67
P_2O_5	0.25	0.22	0.37	0.27	0.23	0.31	0.27	0.27	0.27	0.14	0.22	0.21	0.20	0.14	0.23
MnO	0.19	0.42	0.22	0.10	0.11	0.08	0.11	0.10	0.11	0.11	0.07	0.11	0.13	0.20	0.12
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

NORMS OF AVERAGE ANALYSES

	A	B	C	E	F	G	H	I	J	L	M	N	O	P	Q
Q	12.60	15.06	7.74	13.50	8.16	12.24	12.60	16.26	12.60	7.20	7.80	9.48	10.38	13.98	11.94
or	19.46	16.68	18.90	18.35	16.68	18.90	24.46	11.12	18.35	21.68	18.90	25.02	19.46	12.79	18.35
ab	31.96	27.77	33.54	29.34	29.34	32.49	34.58	29.34	30.39	41.92	31.96	28.30	31.44	34.06	30.92
an	14.18	20.02	16.40	17.24	17.51	17.79	15.01	22.24	17.24	12.51	16.68	15.85	17.51	20.02	17.79
di	6.55	2.62	5.78	4.67	7.60	3.95	2.44	4.91	5.96	6.83	8.40	9.64	5.94	5.28	5.30
hy	8.00	9.32	9.84	10.97	15.38	7.76	4.99	11.27	9.55	2.90	8.85	5.52	7.77	6.86	8.91
mt	5.10	7.19	4.87	3.71	3.02	4.87	3.71	3.02	3.71	5.34	5.57	5.57	6.26	5.34	4.87
il	1.52	0.91	2.13	1.52	1.82	1.44	1.52	1.06	1.52	1.22	1.37	0.15	0.91	1.37	1.37
ap	0.57	0.50	0.91	0.67	0.54	0.70	0.67	0.67	0.67	0.34	0.50	0.50	0.50	0.34	0.54
	99.94	100.07	100.11	99.97	100.05	100.14	99.98	99.89	99.99	99.94	100.03	100.03	100.17	100.04	99.99

A. Average of 248 "superior" analyses of igneous rocks selected by Washington from Roth's tables. See *U.S. Geol. Survey, Prof. Paper No. 28.* Computed by Clarke.

B. Average of 536 British rocks, computed by Harker. "Tertiary Igneous Rocks of the Isle of Skye," *Mem. Geol. Survey, United Kingdom,* 1904, p. 416.

C. Washington's average of 1,811 rocks from all parts of the world. *U.S. Geol. Survey., Prof. Paper No. 14,* p. 106.

E. Average of all data relating to the composition of igneous rocks contained in the laboratory records of the U.S. Geol. Survey (Clarke).

F. Average of 250 analyses of rocks from the Atlantic slope, Maine to Georgia.

G. Average of 113 analyses of rocks from Yellowstone Park.

H. Average of 137 analyses of rocks from Colorado.

I. Average of 195 analyses of rocks from California.

J. Average for all North America. E combined with 398 analyses from Washington's tables.

L. Average of 231 analyses of rocks from Norway, Sweden, and Finland.

M. Average of 420 analyses of rocks from Germany and Austro-Hungary.

N. Average of 250 analyses of Italian rocks.

O. Mean of 1,437 analyses included in B, L, M, and N, plus 122 other analyses of European rocks.

P. Average of 82 analyses of rocks from South America.

Q. General mean of all analyses considered by Clarke.

rated symbols may also be readily determined. Referring to the original paper, already cited, for details of the new proposition, it may be briefly explained in this place.

It is recognized that it is desirable to express in the quantitative system two frequently observed relations of rocks which cannot be shown by the simple magmatic name or the symbol hitherto used. Two rocks often fall in opposite extreme portions of a division, while two others may be found occurring in two adjacent divisions but very near the boundary line. It has been proposed to establish *intermediate* and *transition* zones, the former extending on each side of a given division line one-half the distance to the center points of adjacent divisions and the latter one-fourth of this distance. The boundaries of both intermediate and transition zones are determined accurately by the ratios of the two quantities concerned in the formation of classes, orders, etc. These determining ratios are given in the cited publication.

TABLE OF NORMATIVE RATIOS

	Class $\frac{\text{Sal}}{\text{Fem}}$	Order $\frac{Q}{F}$	Rang $\frac{K_2O'+Na_2O'}{CaO'}$	Subrang $\frac{K_2O'}{Na_2O'}$
A	3.59	0.19	1.88	0.57
B	3.87	0.23+	1.15	0.57
C	3.25	0.11	1.661	0.53
E	3.64	0.21	1.43	0.59
F	2.53	0.13	1.36	0.54
G	4.36	0.176	1.50	0.55
H	6.50	0.17	2.04	0.67
I	3.77	0.26	0.95	0.36
J	3.67	0.19	1.47	0.57
L	5.01	0.09	2.64	0.49
M	3.06	0.11	1.58	0.56
N	3.67	0.137	1.74	0.83
O	3.68	0.15	1.51	0.58
P	4.21	0.21	1.22	0.35
Q	3.76	0.178	1.44	0.56

The transitional position of a rock may be expressed by a compound name, but where it is transitional in more than one respect, as frequently happens, it is desirable to use only the two subrang names expressing the lowest systematic stage in which such transitional relation exists. This usage is illustrated in the following table. In the symbols the transitional relation is indicated by giving in parentheses, beside the number of the division in which a given rock falls, also the number of the division toward which it is transitional.

The intermediate position of a rock is expressed by prime marks placed either before or after the number of a division according to the direction in which the rock is intermediate.

The result of applying these devices to the quantitative classification of Clarke's average rocks is shown in the accompanying table. It appears at once from the symbols of this table that all but three of the average rocks fall in the central half of Class II; that the three exceptions are intermediate to Class I, and that one is within the transitional bounds. The ratios show that not one of these rocks is half-way from the center point of Class II toward Class III.

QUANTITATIVE CLASSIFICATION OF AVERAGE ROCKS

Average of Analyses	Name	Class $\frac{\text{Sal}}{\text{Fem}}$	Order $\frac{\text{Q}}{\text{F}}$	Rang $\frac{\text{Alkalies}}{\text{CaO}'}$	Sub-rang $\frac{K_2O'}{Na_2O'}$
H 137 rocks of Colorado....	Dacose-adamellose	(I) II	4(5)	2′	3(4)
A 248 analyses, Roth's tables	Adamellose-dacose	II	4′	2(3)	(3)4
G 113 rocks of Yellowstone Park................	Harzose-tonalose	′II	4(5)	(2)3	(3)4
J North America.........	Harzose-tonalose	II	4′	(2)3	(3)4
E U.S.G.S. analyses.......	Harzose-tonalose	II	4′	′3	(3)4
B 536 British rocks, Harker	Harzose-tonalose	II	4	3	(3)4
O 1659 rocks, Europe......	Harzose-tonalose	II	4(5)	(2)3	(3)4
Q World's average, Clarke..	Harzose-tonalose	II	4(5)	′3	(3)4
I 195 rocks of California...	Tonalose	II	4,	3	4
P 82 rocks of South America	Tonalose	II	4′	3	4
N 250 rocks of Italy.......	Shoshonose-monzonose	II	(4)5	2(3)	3
M 420 rocks of Germany and Austria.............	Shoshonose-andose	II	(4)5	(2)3	(3)4
F 250 rocks of Atlantic Coast, U.S............	Shoshonose-andose	II	(4)5	′3	(3)4
C World's average, Washington...............	Monzonose-akerose	II	(4)5	2(3)	(3)4
L 231 rocks of northern Europe..............	Akerose	′II	′5	2	′4

With regard to the relation of normative quartz and feldspar, determining the order, it is seen that eight rocks fall within the narrow transitional limits between Orders 4 and 5, half of them on one side and half on the other. Of the remainder all but two are intermediate toward the same boundary line. Of the two rocks coming within the central half of Order 4, B and I, the former is almost on the intermediate line. The extreme range from I to L is less than one-half that of Order 4.

In regard to rang, expressing the quantitative relation of alkalic to calcic feldspars, the new symbols further emphasize the relationship of most of these averages. The range from the most alkalic rock, L, to the most calcic, I, is somewhat less than that of a full rang.

In the relation of potassic to sodic feldspars, a large majority are found to be transitional between dosodic and sodipotassic subrangs, although but two are of the latter. The average of Italian analyses would represent a sodipotassic magma, but even in this case falling on the sodic side of the centerpoint of Subrang 3. The next most richly potassic average is that of Colorado analyses, but it is to be noted with regard to this average that a large number of analyses of phonolite and other sodic rocks from the small Cripple Creek center somewhat obscure the characteristic relative abundance of potash which the writer has long recognized in Colorado rocks.

The use of these new symbols by the writer has convinced him that they afford a good means of expressing in a concise way close relationships or marked differences which it is otherwise necessary to explain in many words. It is to be hoped that petrographers using the quantitative system may become impressed by the status of the transitional rock. It is just as important as any other type, but unless the transitional character is expressed by name or symbol, erroneous impressions may be given. A rock specimen shown by analysis to occupy a transitional position may have come from a mass which as a whole belongs on the opposite side of the division line. It is evident that special care is desirable in the calculation of the norm and the ratios of transitional rocks.

In closing, it seems well to point out to petrographers that it is bad practice to name any division of the quantitative system after the occurrence of a type which is transitional in any respect. The authors of that system have themselves erred in a few cases, but some subrang names recently proposed by other petrographers are particularly unfortunate. It would be well in future, in the writer's opinion, to base a name only on a type falling within the central half of each division of the system.